Fair-weather atmospheric electricity

Basic facts about atmospheric electricity

Atmospheric electricity involves phenomena which are connected with the separation of electric charges in the sub-ionospheric atmosphere (below about 100 km height). In the ionosphere and magnetosphere there occur strong electric currents originating directly from the solar-terrestrial interaction; in the lower atmosphere, there flows a much weaker electric current in the so-called global circuit, which is maintained by the thunderstorm activity. **Charge separation** takes place in three ways:

thermodynamically
: In a thundercloud, small ice crystals collide with rime-growing graupels; the crystals gain positive charge, the graupels negative (the microscopic mechanism is not yet well known).
: Convection in the thundercloud carries the ice crystals to the cloud top, the heavier graupels staying in the mid-cloud: a macroscopic dipole structure forms.

by radiation ionization
: Cosmic and radioactive radiation ionize air, and equal numbers of molecular-size positive and negative small ions are formed; air becomes (weakly) electrically conductive.
: Small ions are also attached to airborne dust (aerosol), which thus regularizes the number of small ions.

by collision ionization
: Lightning and other discharges in the thundercloud ionize air temporarily into electrically conducting channels.

The mobility of electrically charged particles depends strongly on their size and on the density of the medium. The mobility of small ions in the lower atmosphere corresponds to a (terminal) speed of about 1 cm/s in an electric field of 100 V/m. Dust particles are slower by a few orders of magnitude, so that the electric conductivity of air is practically that due to the small ions. In the stratosphere and mesosphere (10 - 90 km) air becomes thinner and cosmic radiation intensifies so that the conductivity increases exponentially with height: while the electric conductivity of air near the ground is of the order of 20 fS/m (femtosiemens/metre), in the ionosphere it is already as high as that of the ground. (In the ionosphere, the electric conductivity becomes also anisotropic: the geomagnetic field has an increasing influence on the ion motion.)

The thundercloud charge centres, accumulating tens of coulombs of electricity, are discharged mainly by lightning: cloud flashes (most abundant) cause mutual neutralization of the centres; the lower centre is also discharged to the ground - by negative ground flashes - and charges up the earth (the positive centre is discharged similarly, but by a smaller amount). An excess charge will be left in the upper positive centre, and it leaks by conduction to the surrounding air, about one ampere per thunderstrom cell. Because of the exponentially increasing conductivity, most of this leak current is guided to the ionosphere, where it is distributed over the globe and charges the upper atmosphere to a potential of about 300 kV with respect to the ground. This "ionospheric potential" maintains the so-called fair-weather current, whose density is about 2 pA/m^2 (picoamperes per square metre). According to Ohm's law, the fair-weather current density and the electric conductivity are associated with a downward electric field, about 100 V/m near the ground. The number of simultaneously active thunder cells ("thunderstorms") over the globe is about 1000-2000, so the whole circuit carries a current of about 1000 amperes.

the human is grounded in practice; the poorly conducting air cannot charge up a ... object. Below a thundercloud, where the ground-level electric field may be tens of kV/m, the situation is different - but then the threat comes from a lightning strike.

The ion balance near the ground can most simply be described by the equation

$$q = an^2 + bnN$$

where q is ionization, n is the density of small ions (both polarities separately, assumed equal), N is the density of aerosol, and a and b are recombination coefficients, which describe the neutralization of ions with each other or with aerosol particles. a and b are both about $1.6 \times 10^{-12}\ m^3 s^{-1}$. Ionization in southern Finland is about $6.6 \times 10^6\ m^{-3} s^{-1}$, one fifth or sixth coming from radioactivity. The small-ion densities are both about $5 \times 10^8\ m^{-3}$ and the aerosol density is more than tenfold, almost $10^{10}\ m^{-3}$.

It should be noted that the notion "dirt increases electric conductivity" is valid for surfaces, for example insulators, but the matter is contrary for air: dirty (dusty) air has poorer conductivity. However, if the "dirt" is a radioactive pollutant, the higher ionization increases the electric conductivity. Such an episode happened in May 1986, when an iodine cloud from the Chernobyl emission arrived at southern Finland: the electric conductivity grew tenfold, but returned to a lower level in a few days, because the half-life of radioactive iodine is 8 days.

Information on international atmospheric electricity research (including lightning research) can be found at the address Atmospheric Electricity HomePage, which among others has a link to a comprehensive English glossary of atmospheric electricity.
